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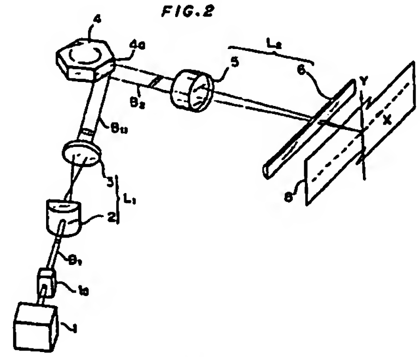
(54) Optical beam scanning system.

(57) An optical beam scanning system is constructed with less optical elements. A light beam (B_1) of parallel rays passes through a first image forming system (L_1). The first image-forming system consists of a cylindrical lens (2) having a refracting power in a direction equivalent to a main scanning direction (X) and a spherical convex lens (3). Focuses of the cylindrical lens and the spherical convex lens are within a prescribed allowance. A light beam (B_{11}) passing through the spherical lens has a character of parallel rays within a vertical plane and a character of convergent rays within a horizontal plane to be focused on a deflection surface (4a). A reflected light beam (B_2) is finally focused on a surface-to-be-scanned (8) through a second image-forming system (L_2).

FIG.2



EP 0 366 039 A2

Optical Beam Scanning System

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to an optical beam scanning system comprising a deflector for deflecting a light beam from a light source and thereby scanning a surface-to-be-scanned by the deflected light beam.

Description of the Prior Art

Fig. 1 is a perspective view of an optical beam scanning system of the prior art. The optical beam scanning system comprises a light source 1, an optical beam modulator 1a, a first image-forming system L_{10}, a deflector 4, a second image forming system L_2 and a recording drum 7. The surface 8 of the recording drum 7 is to be scanned by a light beam B_2; a direction X on the surface 8 vertical to the direction of rotation of the drum 7 is a main scanning direction and a circumferential direction Y is a subscanning direction. The surface 8 will be referred to as "image surface".

The light source 1 emits a light beam B_1 of parallel rays. The light beam B_1 is subjected to ON/OFF control by the optical beam modulator 1a such as an acousto-optic modulator (AOM).

The light beam B_1 then passes through the first image-forming system L_{10} which consists of a beam expander 21 and a cylindrical lens 22. First, the light beam B_1 is expanded to be a light beam B_{1a} of parallel rays by the beam expander 21 consisting of two lenses. Second, the light beam B_{1a} passes through the cylindrical lens 22. The cylindrical lens 22 has a refracting power only along a vertical axis, which is equivalent to the subscanning direction Y. The focal length of the cylindrical lens 22 is the same as the distance between the cylindrical lens 22 and a deflection surface 4a of the deflector 4. Consequently, the light beam B_{1a} is focused on the deflection surface 4a along the vertical axis, but not along the horizontal axis.

The light beam is deflected by the deflector 4 and focused on the image surface 8 by the second image-forming system L_2. The deflector 4 is a rotary polygon mirror; the polygon mirror 4 having several mirror surfaces (or deflection surfaces) 4a rotates to deflect the light beam in the main scanning direction X. The second image forming system L_2 consists of a $f\theta$ lens 5 and a cylindrical lens having a refracting power along the vertical axis. The second image forming system L_2 makes the reflection surface 4a and the image surface 8 conjugate along the vertical axis in terms of geometrical optics.

Resolving power of the optical beam scanning system is inversely proportional to the size of the cross-section of the light beam B_{1a} to be converged. That is, the resolving power of the overall system is increased by expanding the initial light beam B_1 to the light beam B_{1a}.

Further, the second image-forming system L_2 prevents a scanning pitch irregularity, which is caused by a facet error such as inclination of the deflection surface 4a, in the subscanning direction Y.

However, the above system has some disadvantages. The provision of the two lenses of the beam expander 21 naturally renders the larger, the overall optical path length and the number of optical elements; this causes the cost of the first image forming system L_{10} and makes installation and arrangement of optical elements more laborious.

SUMMARY OF THE INVENTION

The present invention is directed to an optical beam scanning system for optically scanning a surface-to-be-scanned in a first direction, comprising: (a) a light source for emitting a light beam of parallel rays, (b) a first optical system provided in a light path of the light beam, comprising: (b-1) a cylindrical lens which has a refracting power only in a direction equivalent to the first direction, and (b-2) a spherical convex lens installed at an image side of the cylindrical lens, the spherical convex lens having a positive refracting power in every direction within a plane normal to an optical axis of the optical beam scanning system, and having an object-side focal point located substantially at the same position with a focal point of the cylindrical lens, (c) a deflector having a deflection surface which is located at an image side focal point of the spherical convex lens, and (d) a second optical system installed between the deflector and the surface-

to-be-scanned for focusing the deflected light beam on the surface-to-be-scanned with respect to each direction on the surface-to-be-scanned.

A distance between the object-side focal point of the spherical convex lens and the focal point of the cylindrical lens may be one millimeter.

Preferably, a focal length of the cylindrical lens is no greater than a focal length of the spherical convex lens.

Spherical aberration of the cylindrical lens may have an opposite sign to spherical aberration of the spherical convex lens.

According to the present invention, an optical path length of the optical beam scanning system can be shortened and the number of optical elemetns can be decreased because a beam expander can be omitted. Accordingly, installation and arrangement of optical elements can be done less laboriously and the total cost of the optical beam scanning system can be decreased.

These and other objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description of the present invention when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a perspective view showing an optical beam scanning system of the prior art;

Fig. 2 is a perspective view showing an optical beam scanning system according to the present invention;

Fig. 3 illustrates a schematic plan view and a schematic elevational view of the optical beam scanning system according to the present invention;

Figs. 4, 6 and 8 are enlarged plan views of a first image-forming system according to preferred embodiments of the present invention: and

Figs. 5, 7 and 9 are graphs of spherical aberration on a deflection surface according to the preferred embodiments.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 2 is a perspective view of an optical beam scanning system according to the present invention. The optical beam scanning system comprises a light source 1, a light beam modulator 1a, a first image-forming system L_1 consisting of a cylindrical lens 2 and a spherical convex lens 3, a deflector 4, a second image-forming system L_2 consisting of fθ lens 5 and a cylindrical lens 6, and an image surface 8.

A column (A) of Fig. 3 is a schematic plan view of the optical beam scanning system and a column (B) of Fig. 3 is a schematic elevational view thereof. The light source 1 and the light beam modulator 1a are omitted in Fig. 3.

The cylindrical lens 2 of rhe first image-forming system L_1 has a positive refractive power along a horizontal axis, which is equivalent to a main scanning direction X on the image surface 8. The spherical convex lens 3 and the fθ lens 5 have positive refracting powers in every direction on a plane normal to the optical path of the optical beam scanning system, respectively. The cylindrical lens 6 of the second image-forming system L_2 has a refracting power along a vertical axis, which is equivalent to a subscanning direction Y on the image surface 8.

In Fig.3 are shown radii r_i of curved surfaces of the lenses 2 and 3, and distances d_i, where the subscript i is an integer from one to five. The radii r_1 and r_2 are defined for the object-side and the image-side surfaces of the cylindrical lens 2, respectively. The spherical convex lens 3 is a lens combined of first and second lenses 3a and 3b. The radii r_3 and r_4 are defined for the object-side and the image-side surfaces of the first lens 3a, respectively. The image side surface of the first lens 3a corresponds to the object-side surface of the second lens 3b. The radius r_5 is one for the image-side surface of the second lens 3b. The distance d_1 is the width of the cylindrical lens 2. The distance d_2 is a distance between the the image-side surface of the cylindrical lens 2 and the object-side surface of the spherical lens 3. The distances d_3 and d_4 are the widths of the first and second lenses 3a and 3b, respectively. The distance d_5 is a distance between the image-side surface of the spherical lens 3 and a deflection surface 4a of the deflector 4.

The following table 1 shows values of parameters concerning the first image-forming system L_1 according to a first preferred embodiment of the present invention:

Table 1

Radius (mm)	Distance (mm)	Refractive Index	Focal Length (mm)
r_1 6.56	d_1 3.0	n_2 1.51509	f_2 12.74
r_2 ∞	d_2 71.3	n_{3a} 1.77748	f_3 63.71
r_3 -80.73	d_3 3.0	n_{3b} 1.83957	
r_4 -12.65	d_4 0.5		
r_5 -28.25	d_5 65.0		

The radius r_i has a positive value when the center of its curvature exists the image side (or the right hand side in Fig. 3) of the curvature. On the contrary, it has a negative value when the center exists at the object side of the curvature. The values of the refractive indexes n_2, n_{3a}, n_{3b} for respective lenses 2, 3a and 3b are defined for a laser beam having a wave length of 633 nm. The focal lengths f_2 and f_3 are those of the cylindrical lens 2 and the spherical lens 3, respectively. Fig. 4 is an enlarged plan view of the first image-forming system L_1 according to the first preferred embodiment of the present invention.

The light beam B_1 of parallel rays, which is emitted from the light source 1 and subjected to ON/OFF control by the light beam modulator 1a, passes through the first image-forming system L_1. Because the cylindrical lens 2 has a positive power only along the main scanning direction, the light beam B_1 after passing through the cylindrical lens 2 converges at a focal point F_2 of the cylindrical lens 2 with respect to the horizontal axis corresponding to the main scanning direction X, as shown in the column (A) of Fig. 3. Even at the focal point F_2 of the cylindrical lens 2, the light beam B_1 behaves as parallel rays parallel to the optical axis.

The focal point F_2 of the cylindrical lens 2 is located within a prescribed allowance around a focal point F_3 of the spherical lens 3. Therefore, a light beam B_{11} after passing through the spherical lens 3 behaves as parallel rays within a horizontal plane parallel to the optical axis and the main scanning direction X as shown in the column (A) of Fig. 3. The allowance is possibly one millimeter, preferably 50 µm, and more suitably 10 µm. Because the focal length f_3 of the spherical lents 3 is greater than the focal length f_2 of the cylindrical lens 2, the width of the light beam B_{11} across a horizontal axis parallel to the main scanning direction X is larger than that of the light beam B_1. In other words, the first image-forming system L_1 functions as an optical expansion system within the horizontal plane. The light beam B_{11} also exhibits a characteristic of convergent rays within the vertical plane as shown in the column (B) of Fig. 3.

As shown in Fig. 4, the cylindrical lens 2 has a negative spherical aberration Δ on the horizontal plane. On the other hand, the spherical convex lens 3 has a positive spherical aberration Δ equal to the negative spherical aberration Δ of the cylindrical lens 2. Therefore, those spherical aberrations cancel each other out. Accordingly, the light beam B_{11} focuses on the deflection surface 4a without spherical aberration within the horizontal plane parallel to the main scanning direction X and the optical axis. Therefore, an image of a line is formed on the deflection surface 4a, extending in the main scanning direction X without spherical aberration in the main scanning direction X.

As shown in the column (B) of Fig. 3, the light beam B_1 propagates in the spherical lens 3 as parallel rays within the vertical plane. The spherical lens 3 is positioned so that the deflection surface 4a corresponds to the focal surface of the spherical lens 3. The spherical lens 3 is so designed as to show small spherical aberration when parallel rays propagate in the lens 3a from the object side. Fig. 5 is a graph of the sagittal spherical aberration in the direction Y on the deflection surface 4a, that is, the transverse aberration. Consequently, the light beam B_1 focused on the deflection surface 4a so as to form a lengthened linear image in the main scanning direction X, with extremely small amount of the spherical aberration in both of the directions X and Y.

After deflected by the deflector 4, the light beam B_2 passes through the second image-forming system L_3 to be focused on the image surface 8. As shown in the column (A) of Fig.3, the light beam B_2 has a characteristic as parallel rays within the horizontal plane parallel to the main scanning direction X and the optical axis. The cylindrical lens 6 has no refracting power in the main scanning direction X. Further, the image surface 8 corresponds to the focal plane of the $f\theta$ lens 5. Consequently, the light beam B_2 is focused on the image surface 8 in the main scanning direction X. On the other hand, as shown in the column (B) of Fig. 3, the light beam B_2 after passing through the $f\theta$ lens 5 becomes parallel rays within the vertical plane parallel to the subscanning direction Y and perpendicular to the optical axis. Because the cylindrical lens 6

has a refracting power in the subscanning direction Y and is positioned so that the image surface 8 corresponds to the focal plane of the cylindrical lens 6, the light beam B_2 is focused on the image surface 8 in the subscanning direction Y. In other words, the deflection surface 4a and the image surface 8 are conjugate in the subscanning direction Y.

According to the first embodiment described above, the first image-forming system L_1 consists of optical elements in a smaller number than that of the optical system L_{10} shown in Fig. 1. Therefore, the optical path length can be shortened and the cost of the first image-forming system can be decreased.

Table 2 shows values of the parameters concerning the first image-forming system L_{1a} according to a second preferred embodiment of the present invention.

Table 2

Radius (mm)	Distance (mm)	Refractive Index	Focal Length (mm)
r_1 10.0 r_2 ∞ r_3 -53.75 r_4 -10.58 r_5 -21.05	d_1 3.0 d_2 23.8 d_3 3.0 d_4 0.5 d_5 50.0	n_2 1.51509 n_{3a} 1.77748 n_{3b} 1.83957	f_2 -19.41 f_3 48.53

The negative value of the focal length f_2 indicates that the cylindrical lens 2 is a concave lens, that is, it has a negative refracting power. Fig. 6 is a plan view of the first image-forming system L_{1a} according to the second embodiment. The focal point F_2 of the cylindrical lens 2 is located within the prescribed allowance from the focal point F_3 of the spherical lens 3. The first image-forming system L_{1a} of Fig. 6 is equivalent to that of Fig. 4. Fig.7 is a graph of the spherical aberration in the direction Y on the deflection surface 4a.

As in the first embodiment, the light beam B_1 is focused on the deflection surface 4a to form a linear image, which is lengthened along the main scanning direction X, with extremely small amount of the spherical aberration in both of the directions X and Y.

Fig. 8 is a plan view of the first image-forming system L_{1b} according to a third embodiment of the present invention. The cylindrical lens 2 consists of two lenses 2a and 2b, and has a positive power as a whole. The definition of the radii r_1-r_6 and distances d_1-d_6 are different from that for the first and second embodiments shown in Fig. 3. Table 3 shows values of the parameters concerning the first image forming system L_{1b} according to the third embodiment.

Table 3

Radius (mm)	Distance (mm)	Refractive Index	Focal Length (mm)
r_1 30.20 r_2 -9.66 r_3 ∞ r_4 119.92 r_5 -13.28 r_6 -30.62	d_1 3.0 d_2 1.0 d_3 85.0 d_4 3.0 d_5 1.0 d_6 59.4	n_{2a} 1.83957 n_{2b} 1.77748 n_{3a} 1.51509 n_{3b} 1.61656	f_2 29.47 f_3 59.78

Fig. 9 is a graph of the spherical aberration in the direction Y on the deflection surface 4a according to the third embodiment.

The spherical aberration of the cylindrical lens 2 is reduced by combining two lenses 2a and 2b. The spherical aberration of the spherical lens 3 is also kept very small. consequently, the spherical aberration on the deflection surface 4a can be reduced as shown in Fig. 9.

In the above embodiments, the focal length of the spherical lens 3 is set lager than that of the

cylindrical lens 2 so that the first image-forming system functions as an optical expansion system by which the light beam B_1 is expanded in the main scanning direction X. However, the first image forming system may not be constructed as an optical expansion system. For example, when a semiconductor laser is employed as the light souce, relatively thick parallel rays can be obtained by setting a collimater lens at the outlet of the semiconductor laser; this negates the necessity of an optical expansion system.

Although the present invention has been described and illustrated in detail, it is clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation. The spirit and scope of the present invention should be limited only by the terms of the appended claims.

Claims

1. An optical beam scanning system for optically scanning an image surface (8) in a first direction (X), comprising: a light source (1) for emitting a light beam (B_1) of parallel rays along an optical axis of the scanning system; a first optical system (L_1) for expanding and focussing the light beam (B_1) on a deflection surface (4a) of a deflector (4) serving to deflect the light beam (B_2) over the image surface (8) in the first direction (X); and a second optical system (L_2) located between the deflector (4) and the image surface (8) for focussing the deflected beam (B_2) on the image surface (8); characterised in that the first optical system (L_1) comprises a cylindrical lens (2) having a refracting power only in a direction corresponding to the first direction (X) and a spherical convex lens (3) located between the cylindrical lens (2) and the deflector (4) and having a positive refracting power in every direction within a plane normal to the optical axis of the scanning system, the spherical convex lens (3) having a primary focal point located at substantially the same position as a secondary focal point of the cylindrical lens (2) and the deflection surface (4a) being located at a secondary focal point of the spherical convex lens (3).

2. An optical beam scanning system in accordance with claim 1, wherein the distance between the primary focal point of the spherical convex lens (3) and the secondary focal point of the cylindrical lens (2) is one millimeter.

3. An optical beam scanning system in accordance with claim 1 or 2, wherein the focal length of the cylindrical lens (2) is no greater than the focal length of the spherical convex lens (3).

4. An optical beam scanning system in accordance with any one of claims 1 to 3, wherein one of the cylindrical lens (2) and spherical convex lens (3) has a positive spherical aberration and the other of the lenses (2, 3) has a negative spherical aberration.

5. An optical beam scanning system according to any preceding claim, wherein the second optical system (L_2) comprises an $f\theta$ lens (5) having a positive refractive power in every direction within a plane normal to the optical axis and a cylindrical lens (6) having a refracting power only in a direction corresponding to a second direction (Y) normal to the first direction (X).

FIG. 1

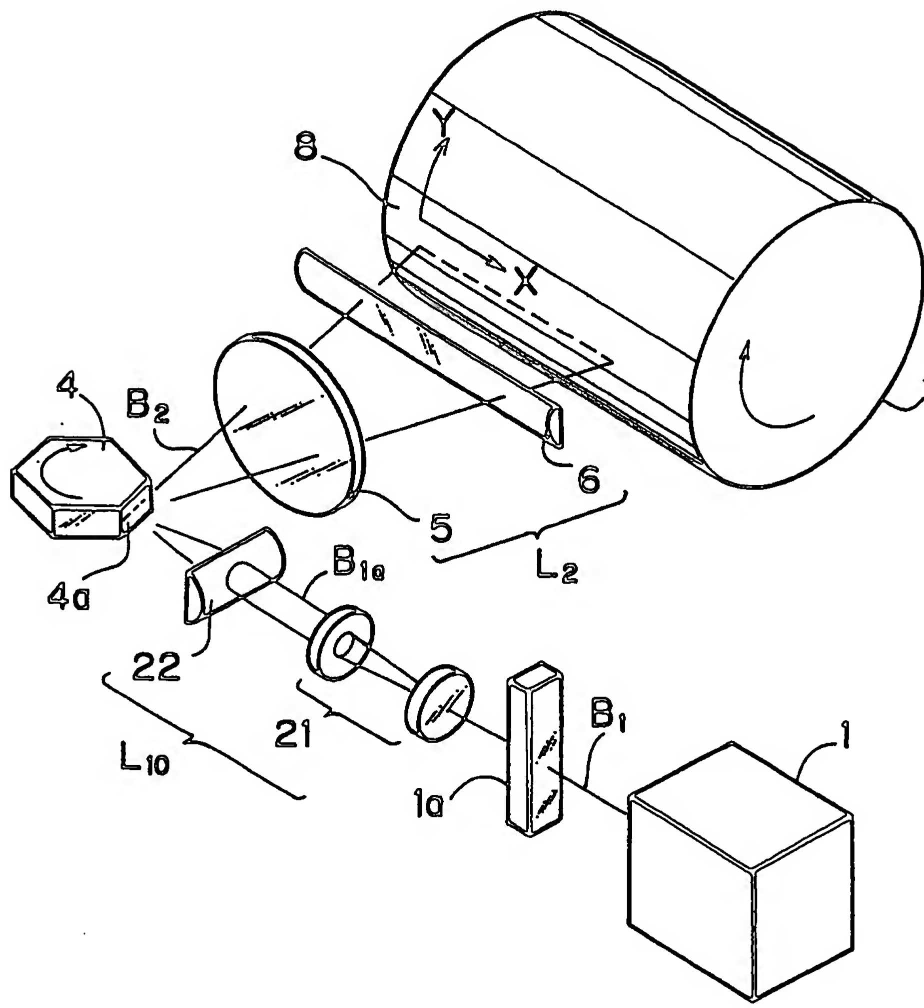


FIG. 2

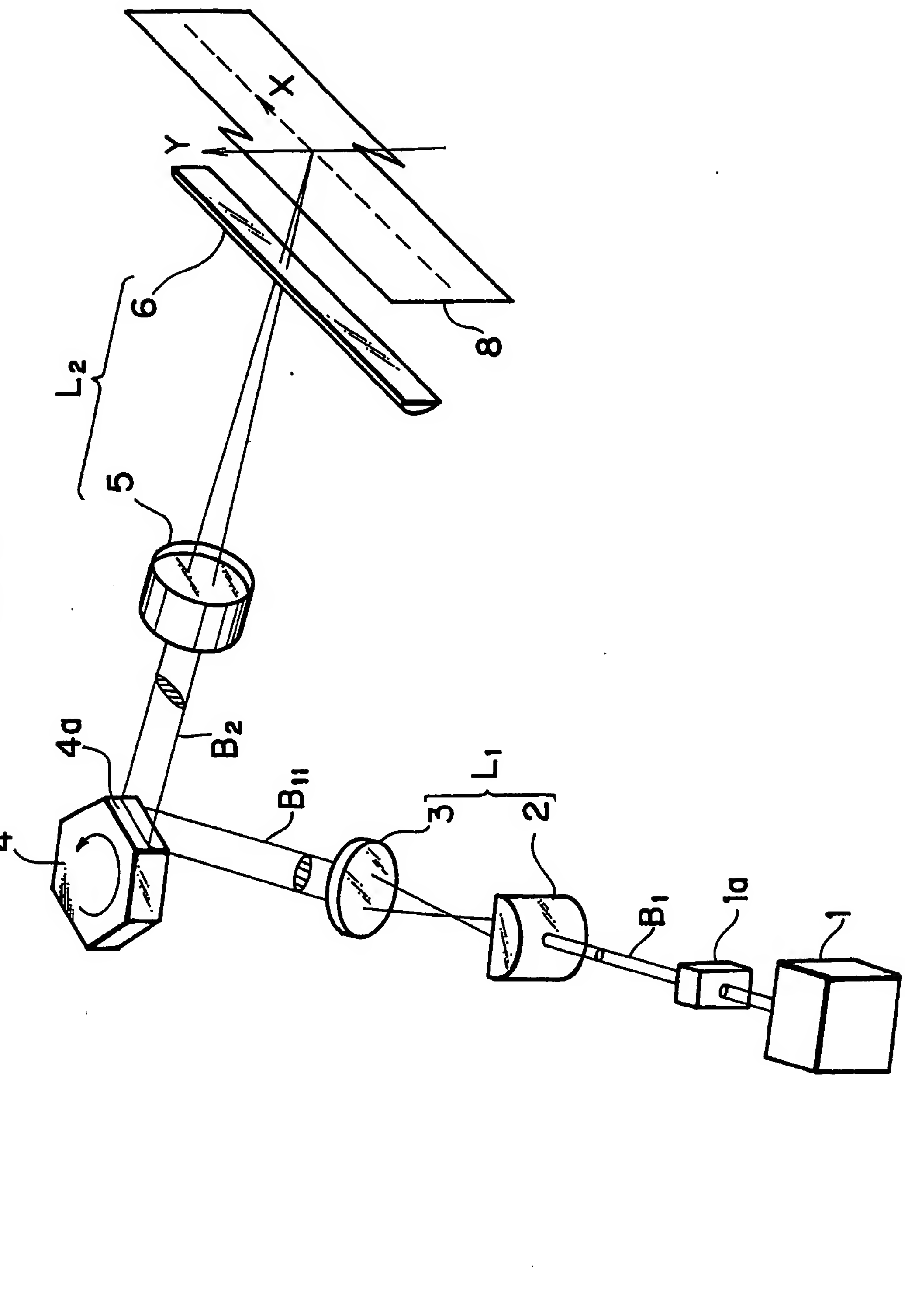


FIG. 3

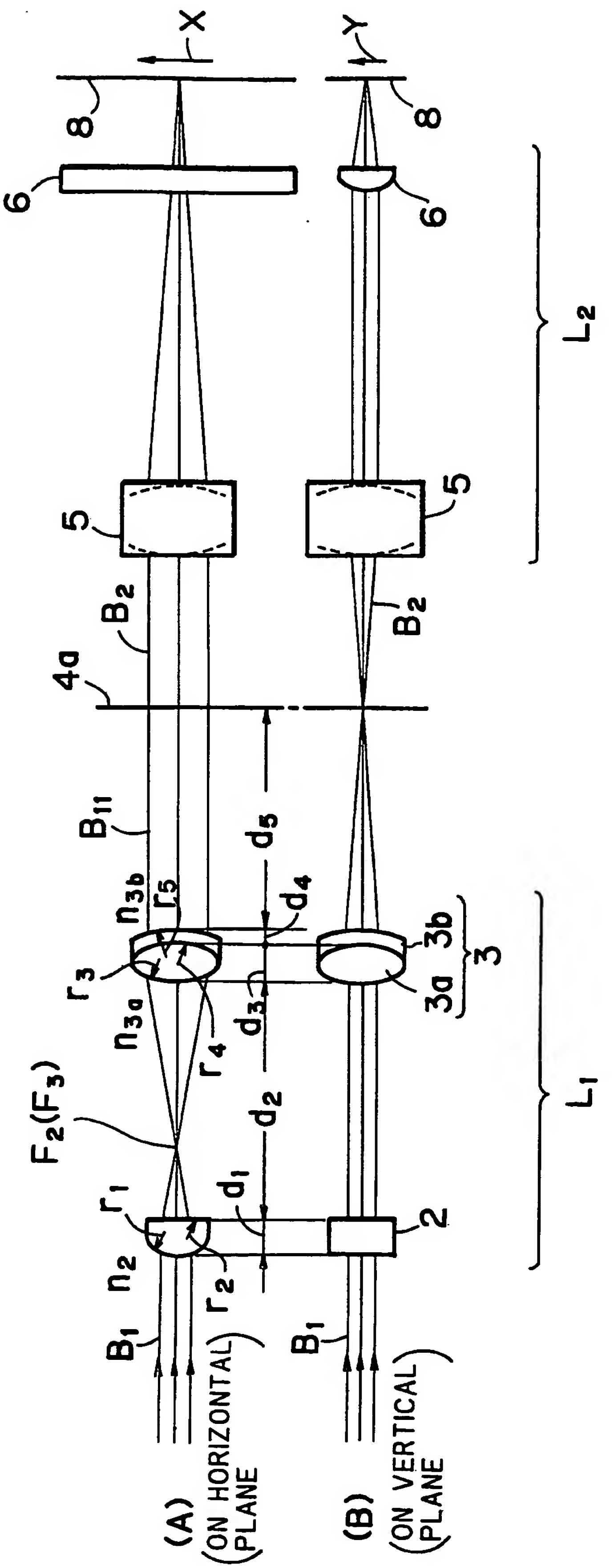

(A) (ON HORIZONTAL PLANE)
(B) (ON VERTICAL PLANE)
B_1
n_2
r_1
r_2
2
d_1
$F_2(F_3)$
d_2
n_{3a}
r_3
r_4
d_3
3a
3
3b
r_5
n_{3b}
d_4
d_5
B_{11}
4a
B_2
5
6
8
X
Y
L_1
L_2

FIG. 4

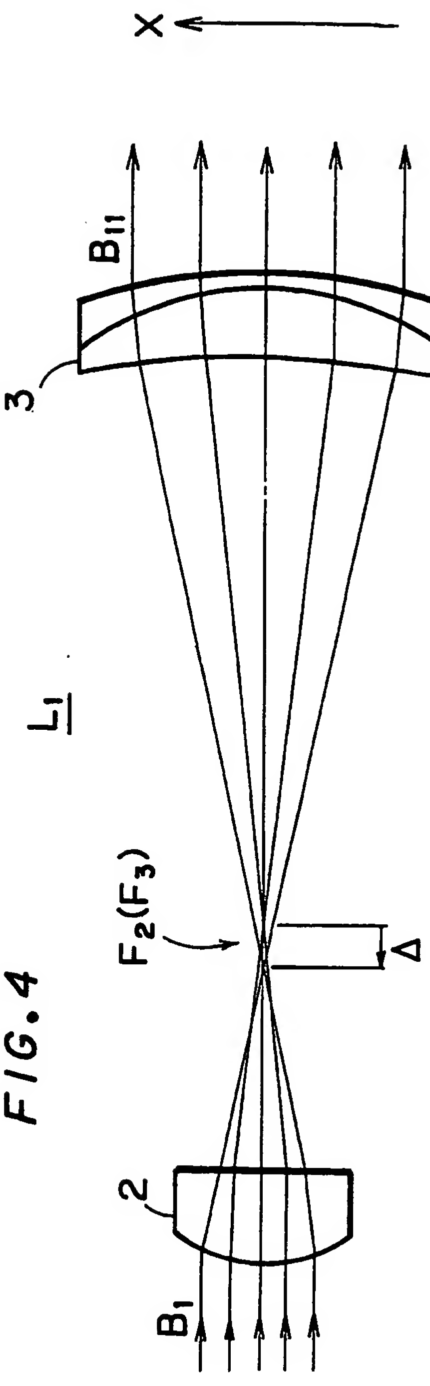
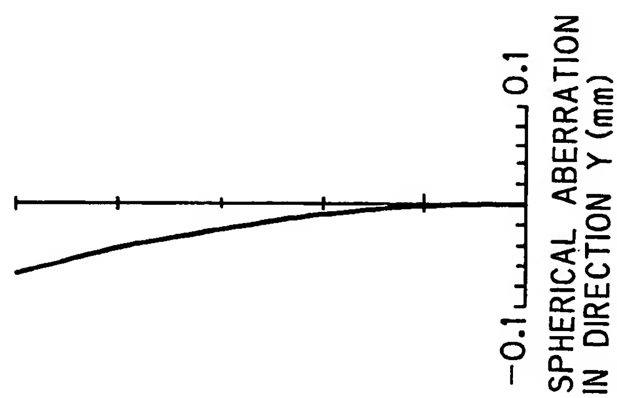

X
B_{11}
3
$\underline{L_1}$
$F_2(F_3)$
Δ
2
B_1

FIG. 5


−0.1
0.1
SPHERICAL ABERRATION
IN DIRECTION Y (mm)

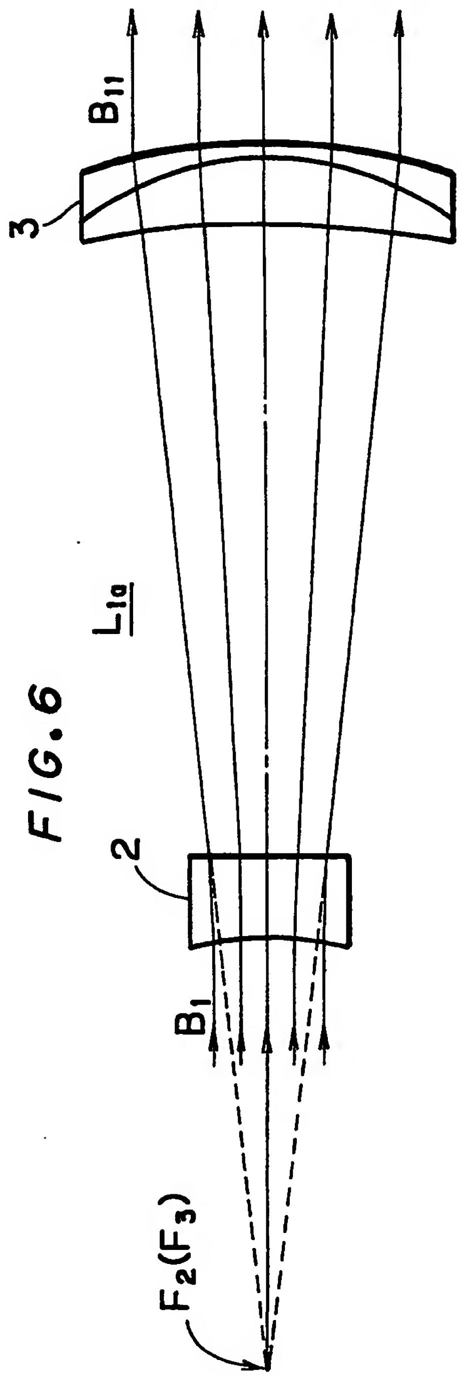

3
B11
L1a
2
B1
F2(F3)

FIG. 6

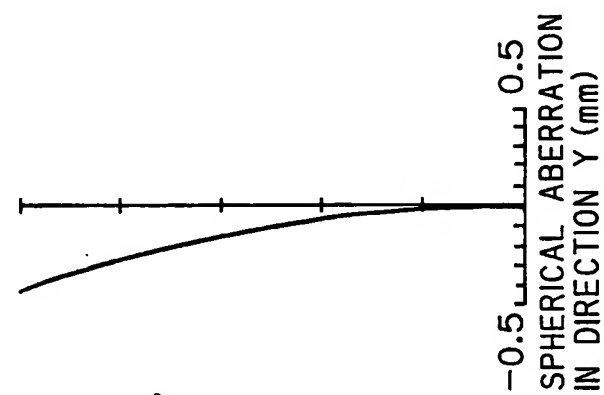

-0.5
0.5
SPHERICAL ABERRATION
IN DIRECTION Y (mm)

FIG. 7

FIG. 8

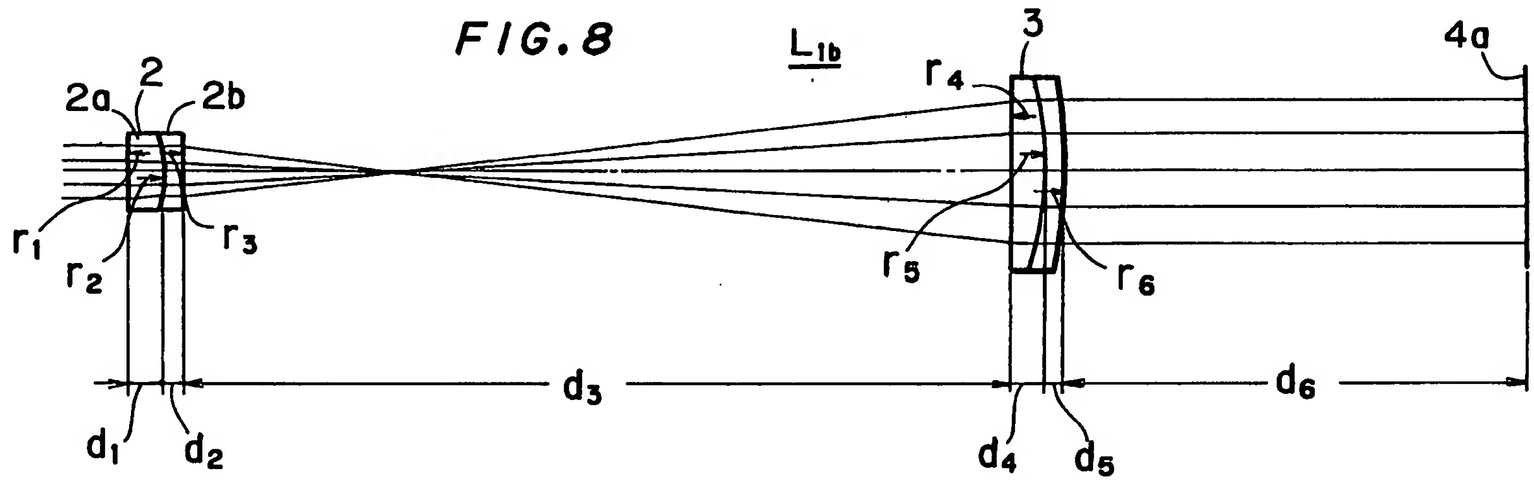
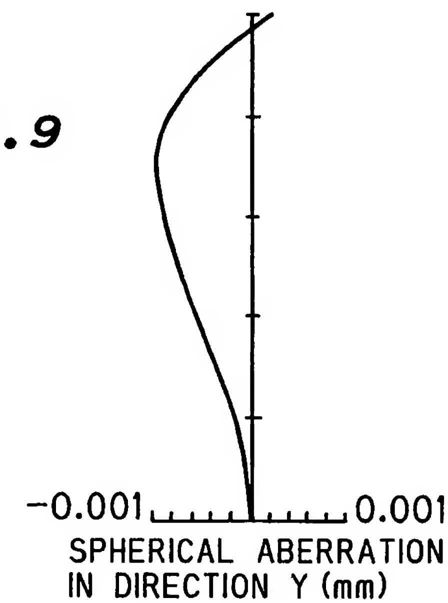

L1b
2a
2
2b
r1
r2
r3
3
4a
r4
r5
r6
d1
d2
d3
d4
d5
d6

FIG. 9


-0.001
0.001
SPHERICAL ABERRATION
IN DIRECTION Y (mm)